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MEMORANDUM REPORT ARBRL-MR-03168

COMPARISON OF SCATTER IN WEAR MEASUREMENTS OF LARGE CALIBER GUNS WITH NOZZLES

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April 1982

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Memorandum Report ARBRL-MR-03168	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* COMPARISON OF SCATTER IN WEAR MEASUREMENTS OF LARGE CALIBER GUNS WITH NOZZLES		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. RICHARD WARD IRVIN C. STOBIE		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BLI Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Armament Research & Development Command U.S. Army Ballistic Research Laboratory (DRDAR-BL) Aberdeen Proving Ground, MD. 21005		12. REPORT DATE April 1982 13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Gun wear and erosion
Stargauge
90 mm Guns
105 mm Guns
155 mm Guns

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)* raj

A common technique to assess wear is to measure loss from a nozzle exposed to propellant combustion gases. Recent experiments in separate laboratories have rated that the scatter from the mass losses recorded for a series of shots with the same propellant is well outside experimental error. This suggests the scatter in data reflects the actual wear process itself and that understanding why the wear process seems erratic should be a key feature of any model of gun barrel wear, if such scatter is also characteristic of wear in guns. (continued on next page)

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To see if the scatter in wear measurements seen with nozzles holds for large caliber guns, a survey was conducted to find wear tests meeting the following criteria: wear vs rounds fired was linear; frequent measurements were made; and the tubes were not chromium-plated. Data from fifteen such tests were collected ranging from 60 mm to 155 mm cannons. It was shown that the scatter in data in the large caliber guns was the same as seen in the nozzles. Typically, the sample standard deviation was 20-30 percent as large as the sample mean wear/round. Not only does this scatter represent a fruitful area of research for understanding how guns wear, but the inherent scatter must be kept in mind when designing gun wear tests.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

A classic method to determine propellant erosivity is to measure the mass loss from a nozzle exposed to combustion gases from the propellant. Recent experiments in different laboratories[1-4] are endeavoring to test a claim made during World War II that propellants containing RDX or HMX are inherently more erosive than conventional propellants.[5] A common feature of the results from each laboratory is that the mean mass loss per shot with a given propellant far exceeds the experimental error from cleaning and weighing the nozzle. This implies that the scatter reflects the erratic nature of the wear process. It also suggests that experiments to test relative propellant erosivity must be designed and interpreted on the basis that the wear is erratic.

In this report results from wear tests in large caliber guns are reviewed to see if the same scatter seen in wear from nozzles appears in guns.

II. SCATTER IN WEAR FROM NOZZLES

The results from experiments in reference 1 serve to illustrate the scatter in data, since a total of twelve shots was fired for each of four propellants, and a radioactive technique devised by Niiler[6,7] was also used to measure actual wear. Table 1 reports the mass loss experiments and Table 2 lists the wear losses measured with the radioactive technique. Figure 1 depicts the scatter in the wear measurement (Table 2). One sees the wear for M5 propellant ranges from 0.49μ to 0.16μ, while the wear for the RDX propellant, HEP, ranges from 0.46 μ to 0.10 μ.

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[1] *R.W. Geene et al, "Erosivity of a Nitramine Propellant," BRL Technical Report TR-02094, August 1978. (AD A060590)*

[2] *J.R. Ward and R.W. Geene, "Erosivity of a Nitramine Propellant with Flame Temperature of M30," BRL Memorandum Report 02926, June 1979. (AD A074346)*

[3] *A.J. Bracuti, L. Bottei, J. Lannon, and L.H. Caveny, "Evaluation of Propellant Erosivity with Vented Erosion Apparatus," Proceedings of the 1980 JANNAF Propulsion Meeting, CPIA Publication 315, March 1980.*

[4] *J.R. Ward, R.W. Geene, A. Niiler, A. Rye, and B. Grollman, "Blowout Gun Erosivity Experiments with Double-Base, Triple-Base, and Nitramine Propellants," ibid.*

[5] *N.H. Smith, "Comparison of the Erosiveness of Propellant Powders," NDRC Armor and Ordnance Report No. A-451, October 1945.*

[6] *S.E. Caldwell and A. Niiler, "The Measurement of Wear from Steel Using the Radioactive Co^{56}," BRL Report No. 1923, September 1976. (AD A030262)*

[7] *R. Birkmire and A. Niiler, "Radioactive Tracers in Erosion Wear Measurements," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, ARRADCOM, Dover, NJ, March 1977.*

TABLE 1. NOZZLE MASS LOSS AS A FUNCTION OF SHOT NUMBER

Shot No.	Mass Losses, mg HFP	M5	M8	M30	M1
1	5.1	5.7	23.1	4.5	2.3
2	2.5	3.9	19.6	3.6	2.1
3	1.6	3.0	12.6	2.8	0.7
4	2.9	4.9	17.2	2.0	2.6
5	3.0	2.7	21.8	3.2	0.9
6	2.9	8.9	15.9	2.2	1.7
7	3.9	4.2	14.3	3.8	2.2
8	3.8	5.7	16.1	2.9	1.2
9	3.2	7.1	16.5	3.3	1.2
10	3.6	4.0	11.9	1.7	1.0
11	2.3	5.2	25.8	2.6	1.4
12	1.9	4.8	17.4	1.8	1.1
Total Mass Loss, mg	36.7	60.1	212.2	34.4	18.4
Mean Mass Loss, mg	3.1	5.0	17.7	2.9	1.5
Sample Std. Deviation, mg	1.0	1.7	4.2	0.9	0.6

TABLE 2. NOZZLE WEAR LOSS MEASURED BY RADIOACTIVE TECHNIQUE

Shot No.	Wear Loss, microns HFP	M5
1	0.46	0.49
2	0.23	0.27
3	0.42	0.29
4	0.20	0.35
5	0.26	0.27
6	0.10	0.42
7	0.28	0.16
8	0.17	0.49
9	0.17	0.55
10	0.33	0.48
11	0.19	0.33
12	0.15	0.53
Total Wear Loss, μ	2.96	4.63
Mean Wear Loss, μ	0.25	0.39
Sample Std Deviation, μ	0.11	0.12

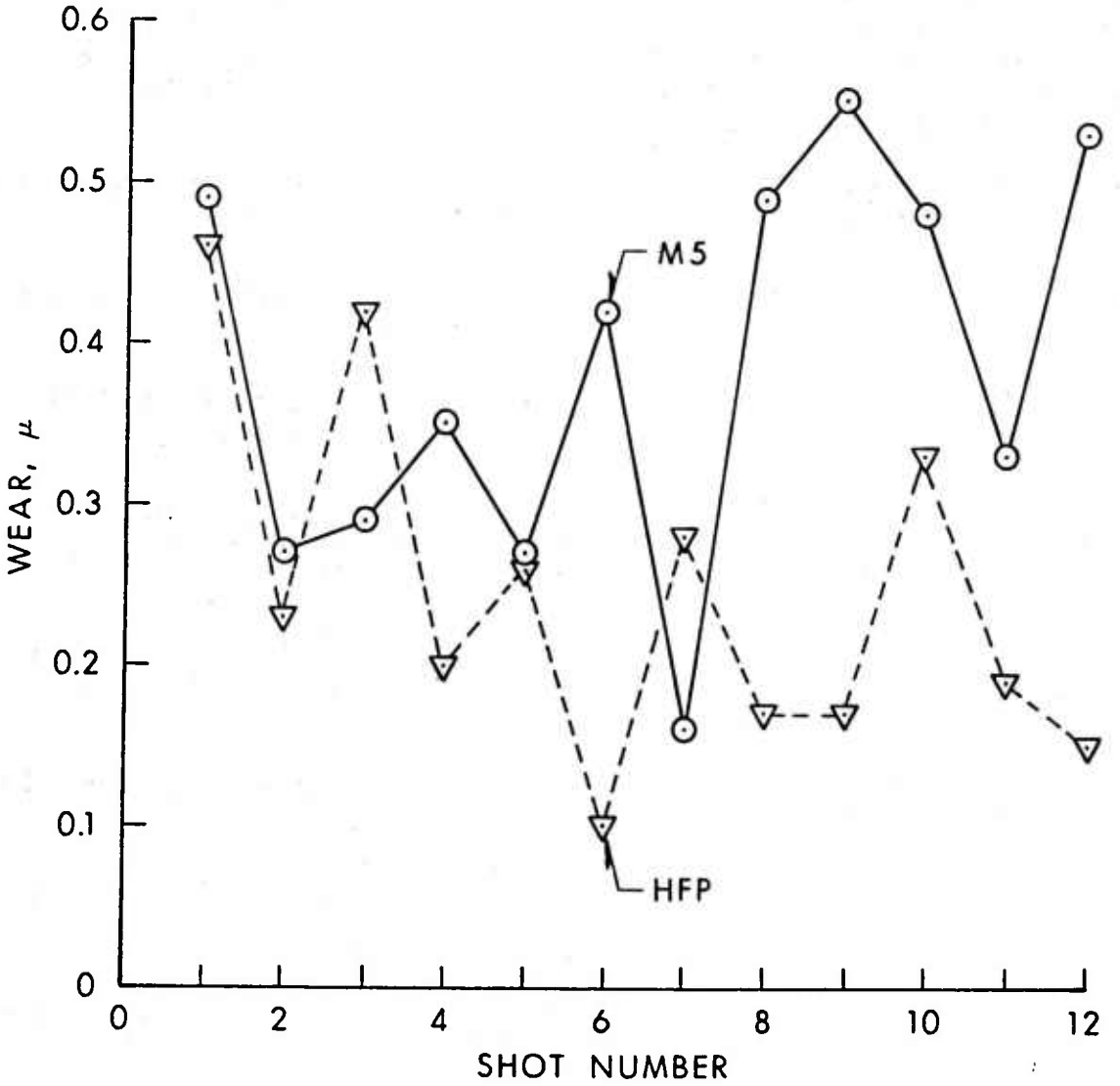

Figure 1. Wear VS Shots Number In Nozzles As Measured By The Radioactive Technique.

III. SCATTER IN GUN WEAR MEASUREMENTS

Wear data was collected for cannons which met the following criteria: frequent diameter measurements were made during testing; tubes were not chromium plated; and wear vs rounds fired was linear over the range considered. In general direct-fire tank cannons wear linearly through the condemnation limit, while wear/round decreases for howitzers after an initial linear portion. Data for howitzers were restricted to this initial period. Table 3 lists the guns having data to meet these criteria.[8-17] Tables 4-18 list wear measurements for these guns.

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[8] *G. Samos, B.B. Grollman, and J.R. Ward, "Barrel Erosion Rate of a 60-mm MC-AAAC Gun," BRL Memorandum Report No. 02857, August 1978. (AD A059804)*

[9] *P.R. Grepps, "Development Tests of Laminar Cooling of Gun Bores, 90-mm, M41," Sixth Report on Ordnance Project No. TW-417, June 1959.*

[10] *R.H. Nelson, "Third Report on the Development Tests of the 90-mm Gun, T119," Fourth Report on Ordnance Project No. TR 3-3045, December 1953.*

[11] *P.R. Grepps, "Component Development Test of Laminar Coolant, Barrel-Wear-Reducing-Additive in Cartridge 105-mm APDS-T M392E1 for 105-mm Gun, M68, Ammunition Components," DPS Report No. 768, January 1963.*

[12] *R.P. Grepps et al, "Final Report of Product Improvement Test of Ammunition Additive Effect on M41 and M68 Gun Tube Life," DPS Report No. 1520, December 1964.*

[13] *L.R. Nealley, "Development and Engineering Tests of Cartridge 105-mm, M393E1 HEP-T and TP-T," DPS Report No. 463, June 1962.*

[14] *T.G. Hughes, "DTII Test of Propelling Charge, 155-mm, XM201E5," APG Firing Record P-82646, July 1977.*

[15] *J.A. Demaree, "155-mm M185 Tube Wear Test of Charge Propelling XM201E5," JPG Report No. 76-601, June 1976.*

[16] *J.R. Struve and J.S. Whitcraft, "Final Report of Engineering Test of Charge, Propelling, 155-mm, XM119, with Projectile, 155-mm HE M107 in the Howitzer SP, 155-mm M109," DPS Report No. 1464, October 1964.*

[17] *P.V. Tague, "DTII of the XM198, 155-mm Howitzer, XM199E9 Tube Wear Investigation," YPG Firing Report 13702, February 1977.*

TABLE 3. SUMMARY OF CANNONS AND AMMUNITION FROM WHICH WEAR DATA WERE COLLECTED

Cal. Cannon	Cartridge/ Propelling Charge	Projectile	Propellant	Nominal Muzzle Vel. m/s	Nominal Peak Chamber Pressure, MPa	Ref.	Remarks
60 MC-AAAC	*	APFSDS	M30	1,524	551	8	All rounds with Wear-reducing Additives
90 T119	*	HVTP-T83	M17	1,250	317	10	
90 T139	*	M318A1-AP-T	M17	914	358	9	Polyurethane foam
105 M68	M392A2	APDS-T	M30	1,485	414	11,12	Polyurethane foam
105 M68	M456A1	HEAT-T	M30	1,174	420	12	TiO_2-wax
105 M68	M467	TP-T	M1	732	165	13	
155 M185	XM201E2	M107	M30	690	205	15	
155 M185	XM201E5	M107	M30	690	205	14	TiO_2-wax
155 M199	XM201E2(mod)	M107	M30	690	205	17	TiO_2-wax
155 M199	XM201E5	M107	M30	690	205	14	TiO_2-wax
155 M126	XM119	M107	M30	690	341	16	

TABLE 4. WEAR OF 60-mm CANNON SN BG-3 FIRING APFSDS PROJECTILES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd. over interval, μ
BF**	1 (0.025)	
14	11 (.28)	18
27	23 (.58)	23
34	29 (.74)	22
47	36 (.91)	14
69	52 (1.32)	19

* *Vertical land diameter measured with a stargauge at 27.50" (527.0 mm) rear face of the tube (RFT). Zero corresponds to diameter of 2.362" (60.00 mm).*
** *Before fire*

TABLE 5. WEAR OF 90-mm CANNON T119 SN 38479 (UNPLATED) FIRING HVTP-T83 PROJECTILE*

Tube Rd. No.	Wear Measurement, mils (mm)	Wear/rd over interval, μ
BF	0	
14	5 (.13)	9.3
54	35 (.90)	19
104	64 (1.63)	15
154	85 (2.16)	11
204	99 (2.51)	7.0
264	127 (3.23)	12

**Vertical land diameter measured with a stargauge at 641.4 mm (25.25 in) RFT. Zero corresponds to 3.546" (90.07 mm).*

TABLE 6. WEAR OF 90-mm CANNON T139 SN 75382 FIRING M318A1 PROJECTILES*

Tube Rd No.	Wear, mils (mm)	Wear/rd over interval, μ
3	4 (0.10)	
103	18 (.46)	3.6
203	41 (1.04)	5.8
303	54 (1.37)	3.3
403	67 (1.70)	3.3
503	77 (1.96)	2.6
603	89 (2.26)	3.0
703	104 (2.64)	3.8
803	124 (3.15)	5.1
903	135 (3.43)	2.8

**Vertical land wear measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 3.543" (89.99 mm)*

TABLE 7. WEAR OF M68 CANNON SN 196 FIRING M467 CARTRIDGES*

Tube Rd. No.	Wear, mils (mm)**	Wear/rd over interval, μ
930	25 (0.64)	
1070	30 (.76)	0.86
1310	24 (.61)	.62
1560	29 (.74)	.52
2260	33 (.84)	.14
2560	35 (.89)	.17
2910	35 (.89)	0.0
4120	43 (1.09)	.17

** Vertical land diameter measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*
***Estimated from data in Figure 39 of reference 13.*

TABLE 8. WEAR OF M68 CANNON SN 3110 FIRING M392A2 PROJECTILES WITH TiO_2 WAX*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
603	7 (0.18)	
903	8 (.20)	0.07
1203	7 (.18)	0.07
1502	10 (.25)	0.23
1803	11 (.28)	.10
2203	14 (.36)	.20
2503	17 (.43)	.23
2903	18 (.46)	.08
3403	20 (.51)	.10
3703	23 (.58)	.23
4103	23 (.58)	0.0
4503	27 (.69)	0.27
5203	30 (.76)	.10
5603	30 (.76)	0.0

**Vertical land wear measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*

TABLE 9. WEAR OF M68 CANNON SN 6601 FIRING M392A2 PROJECTILES WITH TiO_2/WAX*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
2	2 (0.05)	
302	2 (.05)	0.0
602	2 (.05)	0.0
902	3 (.08)	0.10
1202	2 (.05)	.10
1502	3 (.08)	.10
1902	3 (1.08)	0.0
2232	5 (.13)	0.15
2404	6 (.15)	.12
2604	7 (.18)	.15
2784	10 (.25)	.39
3000	11 (.28)	.14
3200	13 (.33)	.25
3358	13 (.33)	0.0
3558	15 (.38)	.25

**Vertical land wear measured with a stargauge 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*

TABLE 10. WEAR OF M68 CANNON SN 3864 FIRING M456A1 PROJECTILES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
604	51 (1.30)	
704	54 (1.37)	0.7
804	62 (1.57)	2.0
904	68 (1.73)	1.6
1004	74 (1.88)	1.5
1104	83 (2.11)	2.3
1204	89 (2.26)	1.5
1304	97 (2.46)	2.0
1404	104 (2.64)	1.8
1504	108 (2.74)	1.0
1624	114 (2.90)	1.3
1724	121 (3.07)	1.7

**Vertical land diameter measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*

TABLE 11. WEAR OF M68 CANNON SN 4360 FIRING M456A1 PROJECTILES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
2	2 (0.05)	
102	5 (.13)	0.8
202	8 (.20)	0.7
302	16 (.41)	2.1
402	21 (.53)	1.2
502	27 (.69)	1.6
702	43 (1.09)	2.0
802	51 (1.30)	2.1
1006	63 (1.60)	1.5
1110	71 (1.80)	1.9
1214	78 (1.98)	1.7
1319	86 (2.18)	1.9
1424	91 (2.31)	1.2
1524	95 (2.41)	1.0
1624	102 (2.59)	1.8
1734	108 (2.74)	1.4
1854	114 (2.90)	1.3
1954	117 (2.97)	0.7

**Vertical land diameter measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*

TABLE 12. WEAR OF M68 CANNON SN 6600 FIRING M456A1 PROJECTILES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
2	2 (0.05)	
102	3 (.08)	0.3
202	9 (.23)	1.5
302	16 (.41)	1.8
602	34 (.86)	1.5
802	48 (1.22)	1.8
1007	63 (1.60)	1.8
1112	68 (1.73)	1.2
1319	80 (2.03)	1.4
1526	96 (2.44)	2.0
1733	110 (2.79)	1.7
1933	117 (2.97)	1.8

**Vertical land wear measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*

TABLE 13. WEAR OF M68 CANNON SN 455 FIRING M392A2 PROJECTILES (POLYURETHANE FOAM)*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
2	2 (0.05)	
52	7 (.18)	2.6
77	11 (.28)	4.0
102	15 (.38)	4.0
127	18 (.46)	3.2
152	22 (.56)	4.0
177	26 (.66)	4.0
207	31 (.79)	4.3
232	36 (.91)	4.8
315	47 (1.19)	3.4
361	55 (1.40)	4.6
422	66 (1.68)	4.6
487	81 (2.06)	5.8

**Vertical land wear measured with a stargauge at 25.25" (641.4 mm) RFT. Zero corresponds to 4.134" (105.0 mm).*

TABLE 14. WEAR OF M126 CANNON SN 16869 FIRING XM119 CHARGE*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
BF	4 (0.10)	
108	11 (.28)	1.7
210	23 (.58)	2.9
310	32 (.81)	2.3
510	58 (1.47)	3.3
711	80 (2.03)	2.8
772	90 (2.29)	4.3
850	95 (2.41)	1.5

**Vertical land wear measured with a pullover gauge 30.00" (762 mm) RFT. Zero corresponds to 6.100" (155.0 mm).*

TABLE 15. WEAR OF M185 CANNON SN 22537 FIRING XM201E2 CHARGES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
1	1 (0.02)	
81	9 (.23)	2.6
120	21 (.53)	7.7
301	32 (.81)	1.5
401	42 (1.07)	2.6
501	44 (1.12)	0.5
601	59 (1.50)	3.8
701	74 (1.88)	3.8
826	77 (1.96)	0.6
951	87 (2.21)	2.0

**Vertical land wear measured with a pullover gauge 39.6" (1006 mm) RFT. Zero corresponds to 6.100" (155.0 mm).*

TABLE 16. WEAR OF M185 CANNON SN 22684 FIRING XM201E5 CHARGES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
1	4 (0.10)	
41	6 (.15)	1.2
151	11 (.28)	1.2
261	17 (.43)	1.4
371	28 (.71)	2.5
481	34 (.86)	1.4
601	39 (.99)	1.1
751	49 (1.24)	1.7
901	54 (1.37)	0.9
1051	65 (1.65)	1.9

**Vertical land wear measured with a pullover gauge at 39.6" (1006 mm) RFT. Zero corresponds to 6.100" (155.0 mm).*

TABLE 17. WEAR OF M199 CANNON SN 72 FIRING XM201E2 (MOD) CHARGES*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
518	11 (0.28)	
598	16 (.41)	1.6
740	20 (.51)	0.7
840	24 (.61)	1.0
1000	30 (.76)	0.9
1092	32 (.81)	0.6
1212	40 (1.02)	1.8
1340	41 (1.04)	0.2
1413	45 (1.14)	1.4
1643	51 (1.30)	0.7
1740	55 (1.40)	1.0
1872	59 (1.50)	0.8

**Vertical land wear measured with a pullover gauge at 41.75" (1060 mm) RFT. Zero corresponds to 6.100" (155.0 mm).*

TABLE 18. WEAR OF M199 CANNON SN 74 FIRING XM201E5 CHARGE*

Tube Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
208	3 (0.08)	
308	8**(.20)	1.2
408	13**(.33)	1.3
508	19 (.48)	1.5
608	23 (.58)	1.0
708	28 (.71)	1.3
808	36 (.91)	2.0

** Vertical land wear measured with a stargauge at 41.75" (1060 mm) RFT. Zero corresponds to 6.100" (155.0 mm).*
***Pullover gage readings.*

Table 19 summarizes the wear data listed in Tables 4-18 as mean wear/round and the sample standard deviation. Table 20 compares nozzle wear and nozzle mass loss with typical values for guns selected from Table 19. The large scatter evident in the gun wear also indicates one should fire a sizeable number of rounds in order to compare relative wear to overcome the inherent scatter in data.

TABLE 19. SUMMARY OF SCATTER IN WEAR MEASUREMENTS IN LARGE CALIBER GUNS

Cannon Cal-mm	SN	Ammunition	Wear Intervals	Wear/rd, μ*	Gauge**
60mm MC-AAAC	BG-3	APFSDS	5	19±4	S
90mm T119	38479	HVTP-T83	6	12±4	S
90mm T139	75382	M318A1***	9	3.7±1.1	S
105mm M68	196	M467	7	0.18±0.5	S
105mm M68	3110	M392A2****	13	0.12±0.1	S
105mm M68	6601	M392A2	14	0.12±0.1	S
105mm M68	3864	M456A1****	11	1.6±0.5	S
105mm M68	4360	M456A1****	17	1.5±0.5	S
105mm M68	6600	M456A1****	11	1.5±0.5	S
105mm M68	455	M392A2***	12	4.1±0.8	S
155mm M126	16869	XM119	7	2.7±1.0	P
155mm M185	22537	XM201E2	9	2.8±2.2	P
155mm M185	22684	XM201E5	9	1.5±0.5	P
155mm M199	72	XM201E2 mod)	11	0.97±0.4	P
155mm M199	74	XM201E5	6	1.4±0.3	S

* *Wear expressed as sample mean and sample standard deviation.*
** *S represents stargauge; P represents pullover.*
*** *Cartridge equipped with polyurethane foam.*
**** *Cartridge equipped with TiO_2-wax additive.*

TABLE 20. COMPARISION OF WEAR IN GUNS AND NOZZLES

Nozzle Mass Loss Experiments	Mass Loss/rd, mg*
HFP	3.1±1.0
M5	5.0±1.7
M8	17.7±4.2
M30	2.9±0.9
M1	1.5±0.6
Nozzle Wear Experiments	**Wear/rd, μ***
HFP	0.25±0.11
M5	0.39± .12
Gun Wear cal-mm	**Wear/rd, μ***
60mm MC-AAAC	19±4
90mm T119	12±4
90mm T139	3.7±1.1
105mm M68 (SN 4360)	1.5±0.5
105mm M68 (SN 6601)	0.12±0.1
155mm M185 (SN 16869)	2.7±1.0
155mm M199 (SN 74)	1.4±0.3

**Wear or mass loss expressed as sample mean and sample standard deviation.*

Table 19 also shows that when many rounds are fired, the mean wear approaches a common value as shown below for the M68 cannon firing the M456A1 cartridges

SN	Wear/Round, μ
3864	1.6±0.5
4360	1.5±0.5
6600	1.5±0.5

Another feature of the data in Table 19 is the comparison between stargage and pullover measurements. Table 21 compares test round numbers where both pullover and stargage readings were taken with the XM201E5 charge.

TABLE 21. WEAR OF M199 CANNON SN 74 FIRING XM201E5 CHARGE

Test Rd. No.	Wear, mils (mm)	Wear/rd over interval, μ
208	4 (0.10)	
308	8 (.20)	1.0
408	13 (.33)	1.3
508	23 (.58)	2.5
608	24 (.61)	0.3
708	30 (.76)	1.5
808	38 (.97)	2.1

The sample means and sample standard deviations are:

	Wear/rd M199 SN 74, μ
Stargage	1.4±0.3
Pullover	1.4±0.8

The higher standard deviation for the pullover is not surprising since the pullover gage is a less precise measuring device.

IV. CONCLUSION

The scatter in wear measurements seen in nozzle experiments is also evident in large caliber guns. Gun wear tests need to be designed with this inherent scatter in mind.

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